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SSC-SDE-6

# SSC-SDE
## SOLENOIDAL DETECTOR NOTES

BEYOND ETA=3
AUGUST 10, 1989

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10 August 1989

# Beyond $\eta = 3$

Abstract

Potential problems with the $\eta$=3 edge are raised, a specialized calorimeter solution due to Partridge is discussed, and it appears that only a large radius coil is compatible with continuous $\eta$ calorimeter coverage.

## Questions

The region beyond $\eta$=3 is usually addressed by a distant end plug near z=15m. This is almost always the case for the solenoidal magnetic detectors in the SSC workshops of the past several years, and is the case for the present picture of the SDE design, as shown in Figure 1 from the Berkeley'87 summer study. Two main questions are asked, but not yet answered, in this note:

- Is the $\eta$=3 discontinuity in the detector a disaster? Will it damage all jets in that region of the detector? Will it severely degrade the $E_T$ measurements for both triggering purposes and final analyses?

- Can the Partridge solution of a liquid scintillator meet the physics requirements of the SDE?

The main purpose of this note is to ask the reader: is this a problem worth solving?

## The $\eta$=3 discontinuity

For 1 TeV jets of particles near the $\eta$=3 edge, the particle populations at shower maximum inside the electromagnetic and hadronic calorimeters will approach $10^4$ and

$10^3$, respectively. For that fraction of the showers which are within a shower width of the edge, a sizable fraction of these low energy particles will leak out into the forward region, making many hits in the forward tracking chambers, and possibly depositing energy in either the forward calorimeters or in the calorimeter modules on the other side of the beam. These energy deposits will be in the "wrong" places, and will contribute to confusion in measuring $E_T$. See sketch in Figure 2. I think that only a "real" simulation (e.g. GEANT) is good enough to answer this question.

This does not now appear to be a concern in CDF, and indeed the diverging magnetic field in the end cap region tends to drive low energy charged particles back into the calorimeter mass (Kephart at SDE August 4 meeting). Nevertheless, I think this problem requires a detailed simulation of this region for the SDE.

A geometry without an $\eta$=3 discontinuity is illustrated by a non-magnetic detector design, such as in the Berkeley'87 workshop, shown in Figure 3. Such a geometry for the SDE means that the large coil option must be taken. There are possibilities that the coil could be "wrapped around" the outer perimeter of the calorimeter, as has been suggested for the "watermelon" design, but this could introduce large axial forces.

### The Partridge solution

Richard Partridge [1] has proposed a liquid scintillator calorimeter tailored to measure $E_T$ directly. This design is shown in Figure 4. Repeating Partridge's rationale briefly, closing off the beam hole gaps would maintain good missing $E_T$ resolution, and provide $\mu$ coverage both for multiple-$\mu$ events and for asymmetry measurements with leptons. Note that no provision for electron measurement is made. The direct measurement of $E_T$ is made by masking out the light signal from small radii so that the response to a fixed energy is proportional to sin $\theta$.

[1] "Closing the Gap: Forward Detectors for the SSC", Berkeley'87 workshop, page 657.

An additional reason for high $\eta$ coverage is to maintain some ability to tag the initial state in WW $\rightarrow$ Higgs. [2].

For the SDE, a robust design might have 1 cm of liquid scintillator between 4 cm plates of stainless steel-clad depleted uranium (DU). This would provide a substantial signal, and the very high density would keep the individual showers of the jet from spreading laterally. Although this is not a compensating ratio of H to U, questions of resolution are not too important for the very high energy showers expected below a polar angle of $\theta$=0.1 ($\eta$=3.). The number of DU+Scint layers is about 40 to achieve $15\lambda_p$. Actually, a stack of DU and liquid scintillator with equal volumes (i.e. 1 cm DU + 1cm liquid scintillator) would be compensating, give four times as much light, and still be fairly compact in the axial direction. However, the showers would spread out laterally 2.5 times more than in the above case since the average density is 2.5 times less.

Since this region is already confined to a small radius, and because it is so simple, there is little extra expense in going out to $15\lambda_p$.

The large light signal can be measured with a photodiode embedded near the outer radius. (The optical collection efficiency may be low, but there is a lot of light, so for now let's ignore this problem.) In fact, it is desirable to have two photodiodes for each liquid volume, and to choose the lesser of the two. This would avoid the problem of a large, fake signal due to a shower making a "direct hit" on a photodiode. There is an embarrassingly low number of channels in this system, so that some expense could be put into an improved fast photodiode design.

Hermeticity in this $\eta$=3 region is important. I see no reason why this device could not be sensitive out to nearly its physical (i.e., uranium) edge. The photodiodes could be embedded within the liquid volume, behind and between the uranium, and the

[2] Gutay, et al., Berkeley'87

number of coax cables going out is very small. The only "daylight" seen by particles would be due to the $\eta \leq 3$ calorimeter.

### Discussion

The best choice for this region is just to continue the small $\eta$ calorimeter smoothly into the large $\eta$ region, and stop when you hit the beam pipe. The problem here is that liquid ionization detectors (LID's) with a 50-100 ns shaping time cannot tolerate the high hit rates in this region, while scintillators are fast enough but probably cannot take the radiation damage. This $\eta$ limit for LID's should be calculated, since it determines where the $\eta$ edge (or discontinuity) has to be in the first place.

Now, there is still a discontinuity at $\eta$=3 even with the Partridge solution. The $\eta \leq 3$ calorimeter measures energy in a volume, as a good calorimeter should, while the Partridge device measures $E_T$, and looses the separate information on energy and position. A jet which straddles these two devices may also be badly damaged. I will solve this problem, probably during September, by scanning jets across this boundary in a simulation.

In any case, I think that at least the geometry (if not the technology) of the front faces of these devices should be continuous, and maybe look like Figures 5a or 5b. These designs are no bigger than the nominal SDE shown in Figure 1, and in fact have a smaller calorimeter volume, and in Figure 5b a smaller field volume as well.

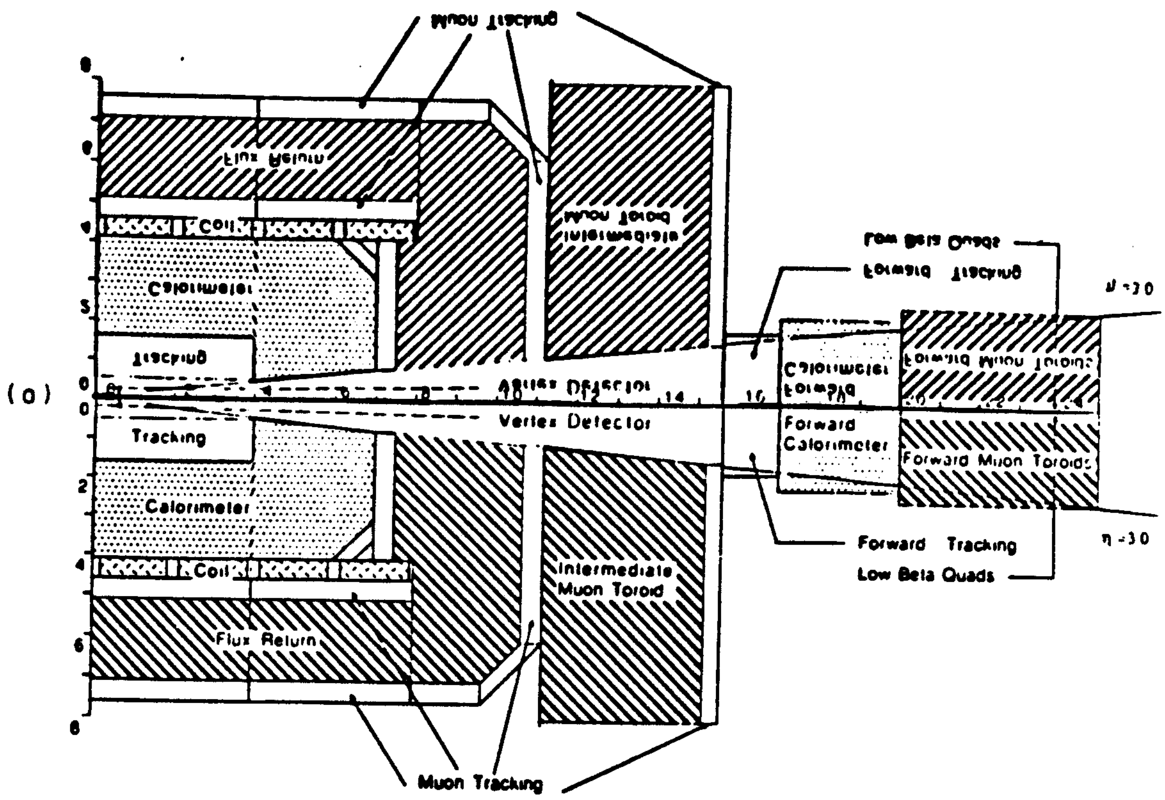


FIGURE 1 the SDE with $\eta > 3$ detectors.

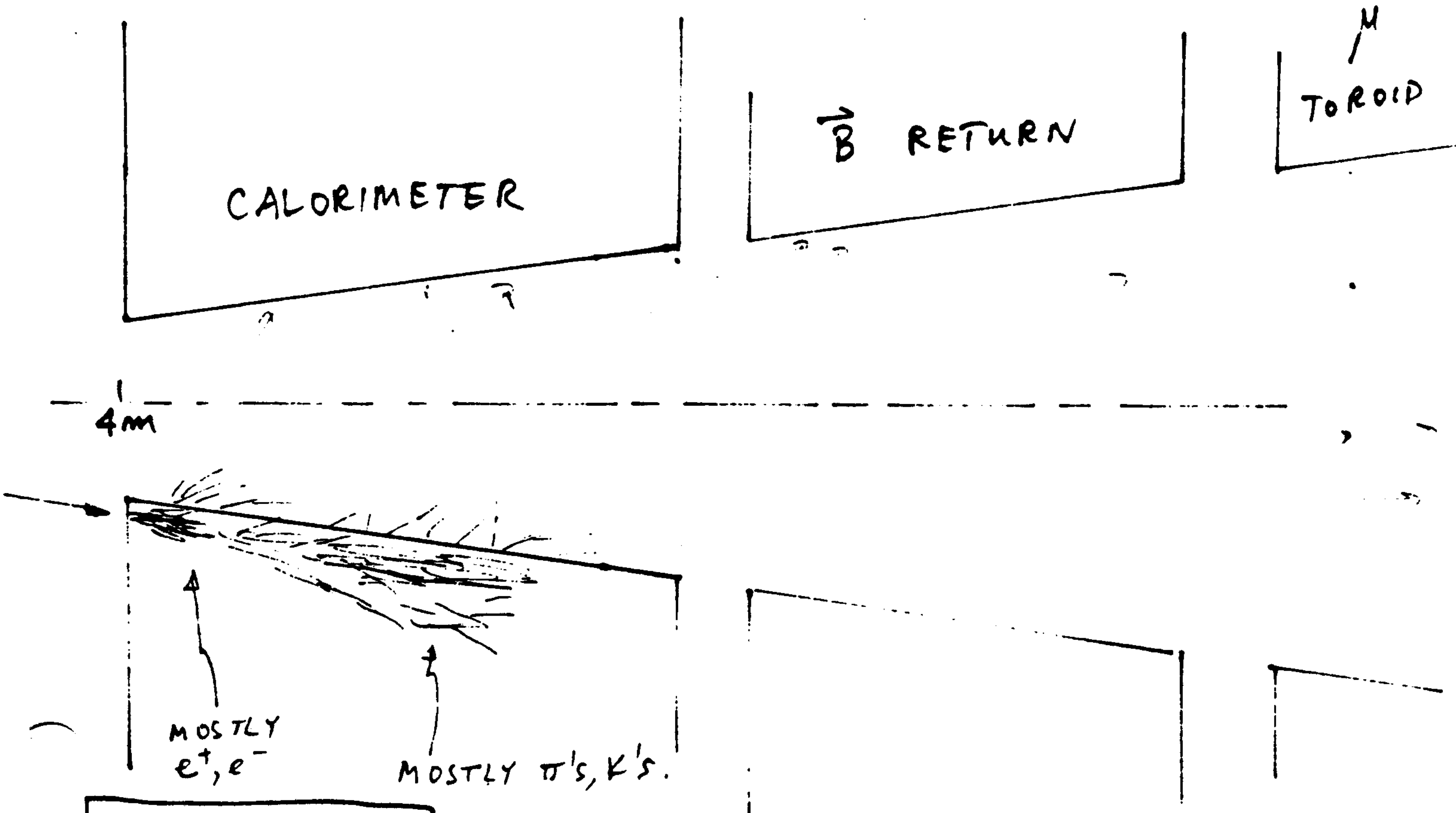


FIGURE 2

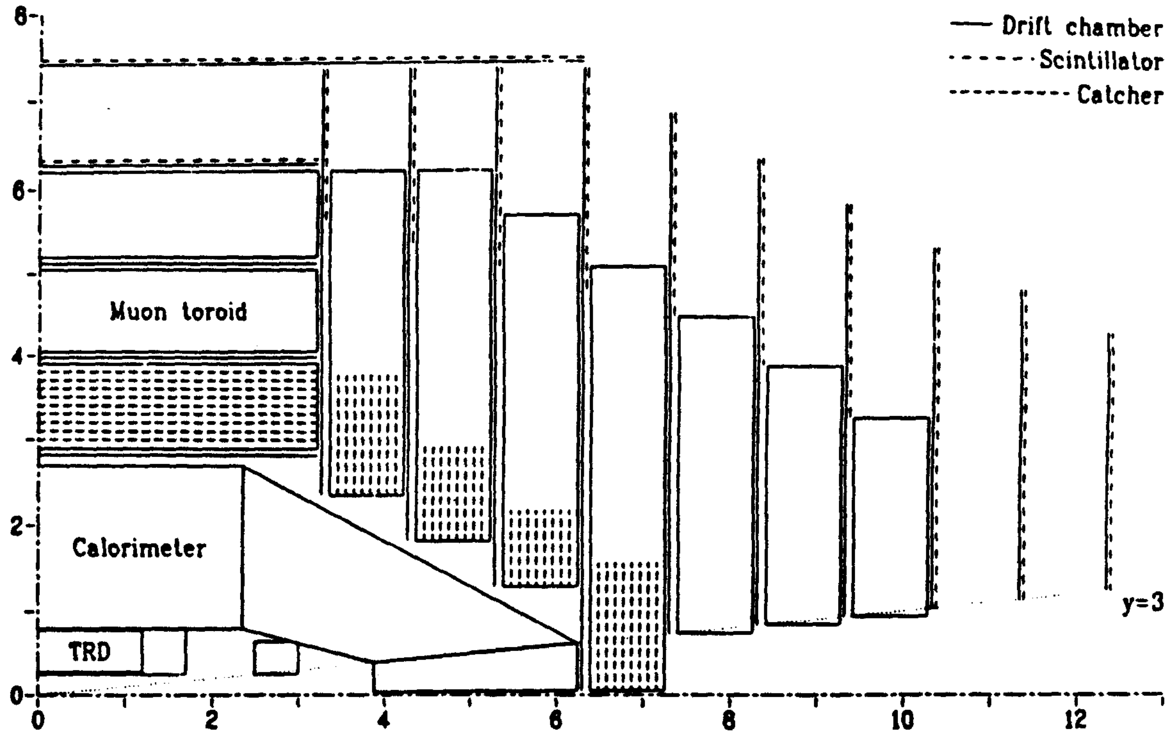


**Fig. 1a. Elevation View of the "Non-Magnetic Detector."**

FIGURE 3

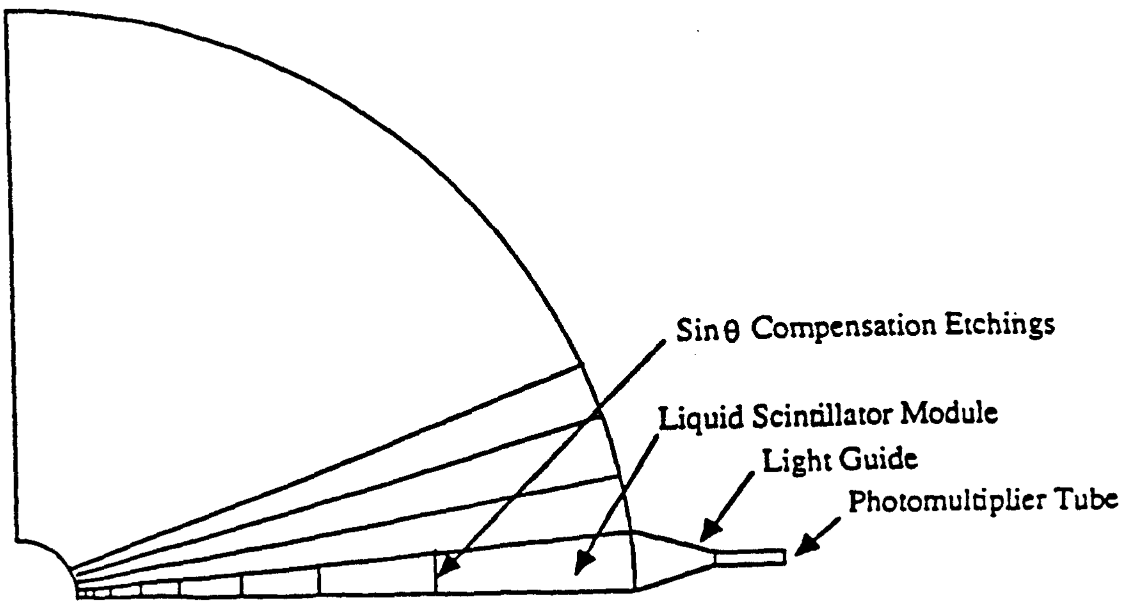


Fig. 3 Diagram showing construction of liquid scintillator sampling module for a forward detector calorimeter.

FIGURE 4

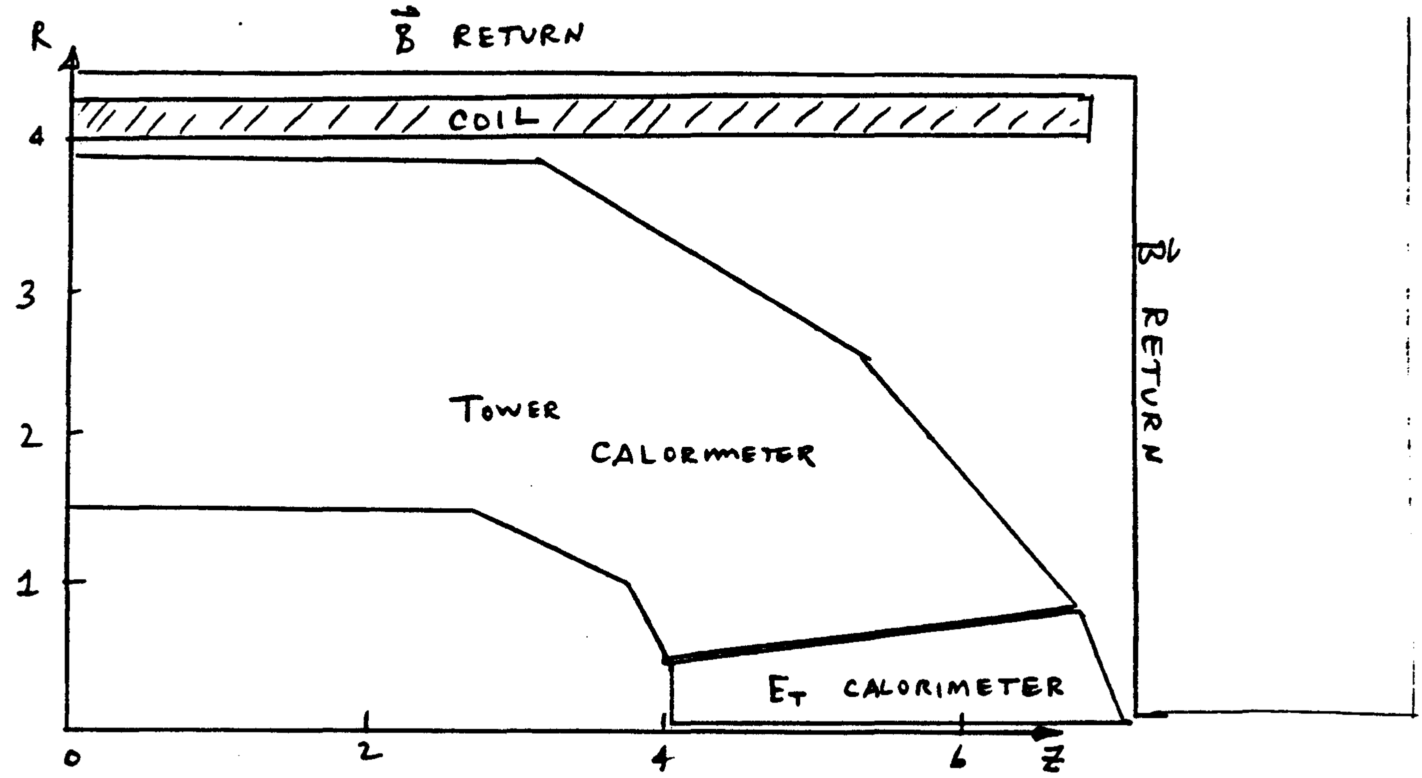


FIGURE 5a.

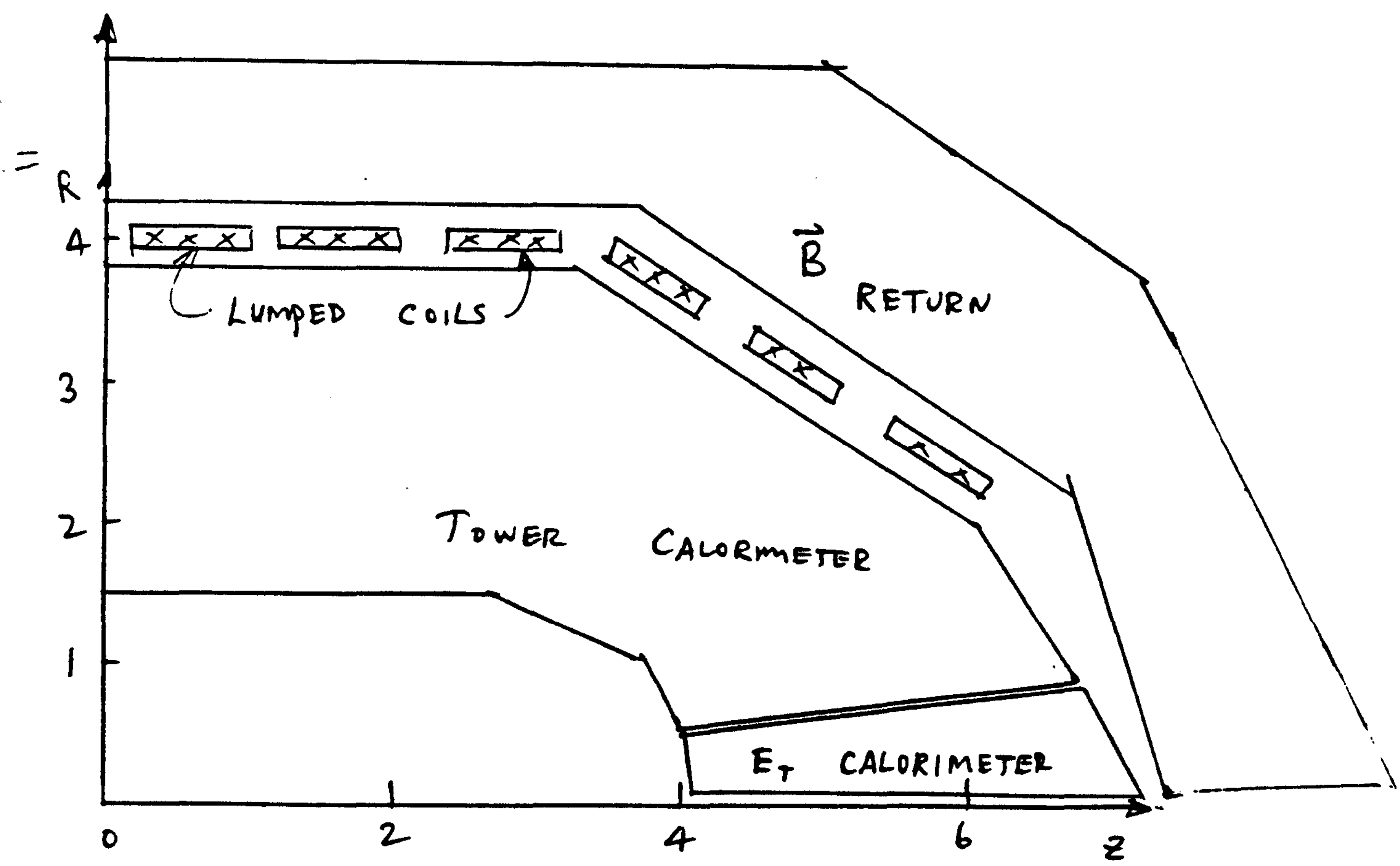


FIGURE 5b

J MN



# Lateral Segmentation

Abstract

Three criteria are used to assess the lateral segmentation needs of an SSC calorimeter: (i) W $\rightarrow q\bar{q}$ mass resolution, (ii) electron ID, and (iii) W $\rightarrow q\bar{q}$ identification. It is concluded that a hadronic segmentation of .04 and an electromagnetic segmentation of .02 are required.

John Hauptman
25 June 1989

## Lateral Segmentation

The question of lateral segmentation in SSC calorimeters has been addressed for several years (1984 to 1989) and by many people. I am surely not aware of all the work, but I will revisit this question by collecting and plotting calculations from the following sources:

Fernandez, et al., Snowmass 1984, p. 107.
Protopopescu, Snowmass 1986, p. 180.

Freeman and Newman-Holmes, Berkeley 1987, p. 673.

Bay, et al., SSC-202, Jan. 1989.

Bengtsson, et al., FSU-SCRI-89-01, Jan. 1989.

There are three figures-of-merit which have been commonly used to assess the quality of an SSC calorimeter, (i) the W $\rightarrow q\bar{q}$ mass resolution, (ii) electron identification, and (iii) the relative reconstruction and identification efficiencies of W $\rightarrow q\bar{q}$ and QCD jets which fake a W decay. The first two are "trivial" to do, while the third requires full-event simulations of large "data" samples.

The results of these calculations for (i) are shown in Figure 1. It must be noted that for most of these numbers I have read the FWHM from a plot, then divided the FWHM by 2.36 to get a rms width, $\sigma$. Also, as far as I can tell, all groups used a tower geometry with uniform $\eta-\phi$ segmentation which was equal for both electromagnetic and hadronic sections, *except* for Fernandez/1984, in which the hadronic section was a factor of two more coarse than the electromagnetic. Therefore, the "effective" combined segmentation for this calculation is that value plotted on the abscissa, i.e. for .01 electromagnetic and .02 hadronic, the effective segmentation is taken to be .015. Finally, I have also included a point from UA1 data (Carboni, Vanderbilt 1987) at $\Delta\eta$ = .17 showing their calculated resolution of 7.9±0.5 GeV. Counting bins in their data, in which the W and Z are not mass-resolved, I agree with this number.

The numbers from Bay, et al., should be disregarded. The points on this plot are from their Table 1, Case 4, which roughly corresponds to the calculations by the other parties, but their numbers in Table 1 do not at all represent the distributions they show in their figures. I understand that there will be an erratum to this report.

I was surprised by the good agreement among these calculations. Anyway, apparently the W mass resolution does not improve below a segmentation of $\Delta\eta = \Delta\phi$=.05 in the central region. Presumably, the mass resolution at very small segmentation is limited by the energy resolutions assumed for the calorimeters in these calculations, although that is not proven. Freeman and Newman-Holmes did calculate the mass resolution versus assumed calorimeter energy resolution, but only for some nominal segmentation, not a very fine segmentation. Between "perfect" energy resolution and some nominal energy resolution, the W mass resolution degraded by about 20%. (Freeman and Newman-Holmes, Figure 3.)

**A reasonable conclusion based on W mass resolution is that going below $\Delta\eta = \Delta\phi$=.05 would not be worth the expense.**

The second figure-of-merit is electron identification or tagging. This largely refers to an isolated electron, but electrons buried in jets, or near the edges of jets, may also be of interest. People have used several criteria, but a simple criterion is just to require that a candidate electron tower be surrounded by quiet (say, less that 5%) towers. Many people have found answers to this problem, and I will just plot their answers to the question "what segmentation is required to identify electrons" in Figure 2. The numbers, with references, are below.

| reference | comments | $\Delta\eta$=$\Delta\phi$ |
|---|---|---|
| Non-Magnetic Det, Berk'87, p.472 | 2 cm × 2 cm at 1 m | .02 |
| Compact Det, Berk'87, p.388 | from Baltay, et al., Snow'84 | .03 |
| LSD, Berk'87, p.340 | "e/$\pi$ could be better if $\Delta\eta$ finer" | .02-.03 |
| Partridge, Berk'87, p.657 | t$\rightarrow$e tagging near $\theta$=0 | .02 |
| Williams, Snow'86, p.327 | | .02 |
| Baltay, et al., Snow'86, p.355 | "the finer the better" | .03 |
| "Identification of e-", Snow'86, p.420 | | .01-.02 |

The "mean" here is about $\Delta\eta$=$\Delta\phi$ = .023. These numbers are for an unassisted calorimeter. There is a further point that one might get away with a coarser segmentation if one uses a precision pre-radiator or a shower-max chamber as in CDF. These require some study in the SSC environment. I fear that some wishful thinking is taking place here, and that event pile-up and stray tracks from jets bent into a candidate electron tower will degrade the identification. So a careful calculation is required.

Permit me to ramble a minute here. Whenever it is possible to make direct and robust measurements in a detector, such that *the raw measurements themselves give you the answer*, then that is best. Ancillary information (e.g. from a pre-radiator or shower-max chamber) cannot often be used in a first level trigger because the geometrical association cannot be made that quickly. The Berkeley TPC is a good example of a detector whose raw data contain exceptionally good information. The big Berkeley bubble chambers are another example, and both of these devices were workhorses for two generations of good physics.

Although people with different tastes and different experiences with detectors will arrive at different conclusions, mine is that there is no substitute for direct identification, especially for electrons at both the trigger and refined analysis levels. Since electrons are so important, there should be a confirming measurement which can be employed at the third level trigger and in the analysis.

**A conclusion based on electron identification is that a segmentation of $\Delta\eta$=$\Delta\phi$ = .02 in the electromagnetic calorimeter is driven by the need to identify isolated electrons.**

The third, most difficult figure-of-merit is the calorimeter capability to identify hadronic W decays, W $\rightarrow q\bar{q}$, and to distinguish these W's from ordinary, copious QCD fragmentations. As far as I know, I am the only one to do this problem as a function of segmentation, although Protopopescu has done it at $\Delta\eta = \Delta\phi$=.05. It requires generating tens of thousands of events with Pythia/ISAJET and passing the stable, interacting particles through a good calorimeter simulation program. I store separately electromagnetic and hadronic towers with energies above 0.1 GeV for a segmentation of $\Delta\eta = \Delta\phi$=.01, and then I combine towers to generate event records with .03, .05, etc. I have generated two large event samples: (1) gg $\rightarrow$ Higgs $\rightarrow W^+W^- \rightarrow \ell\nu + q\bar{q}$ and (2) qq $\rightarrow$ qW $\rightarrow \ell\nu$ + q. The quarks give jets, and the game is to distinguish the quark-jet in process (2) from the two W quark-jets in process (1). The W decay to light quarks is kinematically like $\pi^0 \rightarrow \gamma\gamma$ decay, and gives two distinct jets most of the time, so there are two clumps in the calorimeter. As the W energy approaches 1 TeV, these clumps begin to coalesce. For a highly asymmetric decay in the W center-of-mass, one jet can go backwards and be very slow in the lab, and the other carries most of the energy into one clump in the calorimeter. The single quark from process (2) gives one clump, but some fraction of the time, like $\alpha_s$, there are two or more secondary jets, and the energy pattern in the calorimeter can resemble a W decay. We have to trust that our simulation codes get this right. By doing some complicated pattern recognition and event reconstruction (including the missing $\nu$), I find that the efficiency to keep W's relative to the probability for a jet to fake a W is about 100, that is, you can reduce the QCD quark background by 100 relative to the W signal. The dependence of these efficiencies on the lateral segmentation is shown in Figure 3 (from Snowmass 1984 and from Berkeley 1987). There is a long story about whether or not the simulation codes generate the proper amount of multi-jets or not. So as a test, I forced Pythia to make more multi-jets and, as expected, the rejection against these multi-jets deteriorates (by a big factor, too, so life may be very difficult with W $\rightarrow q\bar{q}$).

In addition, there are two handles on this process which can serve to improve its effectiveness. One is the capability to tag the initial WW state (Gutay, et al., Berkeley 1987, p. 788), and the second is that quarks from the W will have a multiplicity corresponding to 41 GeV partons, whereas the QCD background jet will on the average have a much larger multiplicity. (Lee Pondrom, ANL meeting, June 13-15, 1989). Neither of these handles have yet been employed.

I don't think Bob Cahn is right about W $\rightarrow q\bar{q}$ identification not being possible, since I have shown using both ISAJET and Pythia that it is possible to obtain a background rejection of about 100. If both ISAJET and Pythia are wrong, and multi-jets are more abundant, then many other design calculations are also wrong. Seeing the Higgs as a $3\sigma$ bump may be marginal, and in this circumstance confirmation from another decay mode would be vital. Giving up and making the segmentation worse only guarantees that the WW mode will be impossible.

**In any case, my conclusion is that beyond a hadronic segmentation of $\Delta\eta$=$\Delta\phi$ = .04, combined with an electromagnetic segmention of .02, the W $\rightarrow q\bar{q}$ identification degrades rapidly.**

One final comment: we do all of these detector designs with the standard model in mind, but if we ever want to see past the end of our nose, then we should over-design just in case something more interesting and demanding than the standard model develops. So why not design for the Higgs, then make the calorimeter 50% better *for no good reason.* This is not fiscally irresponsible: an increase in channel count by a factor of 2 may only increase the overall cost of the calorimeter system by a few percent.

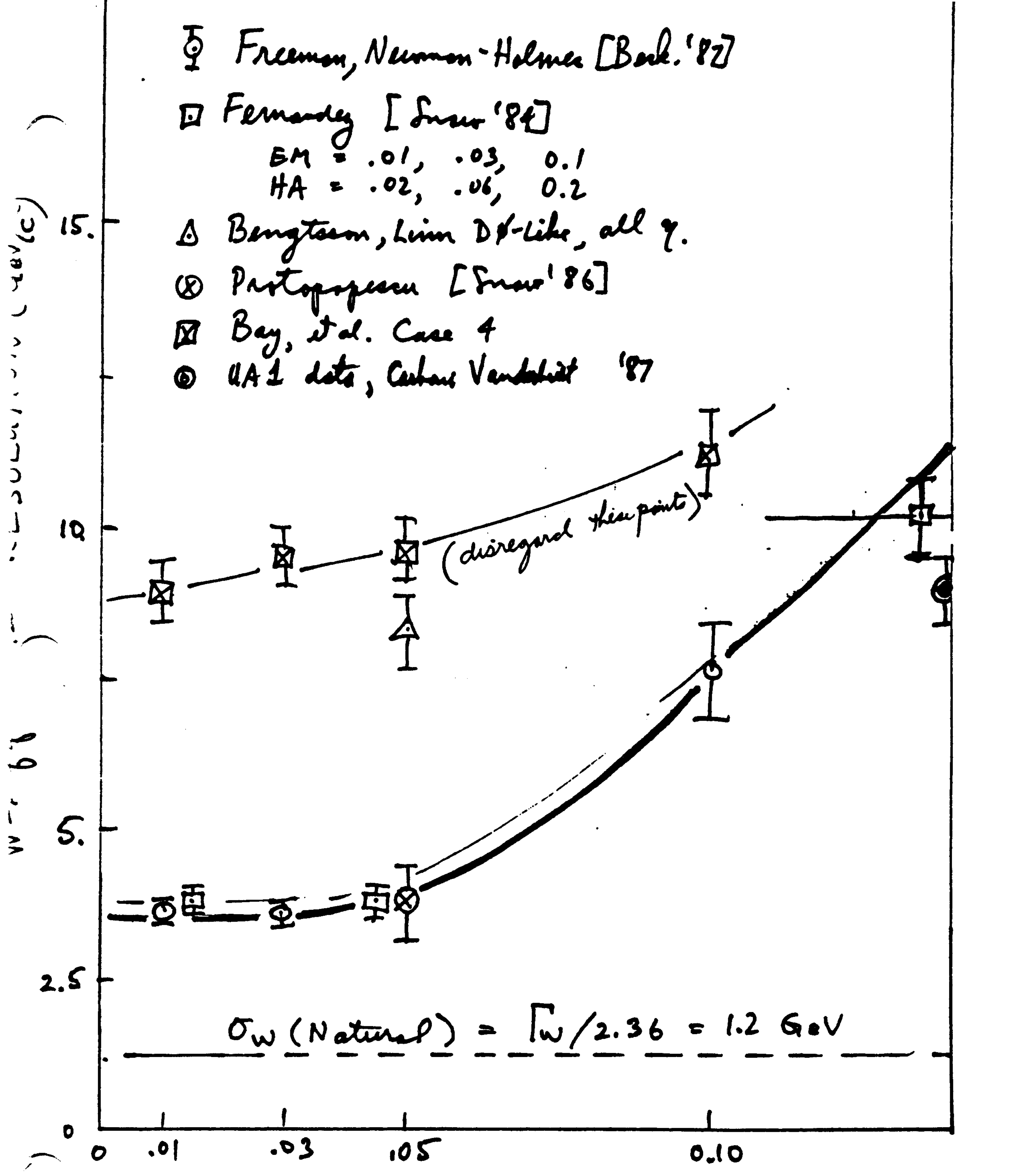


Figure 1: η, φ LATERAL SEGMENTATION →

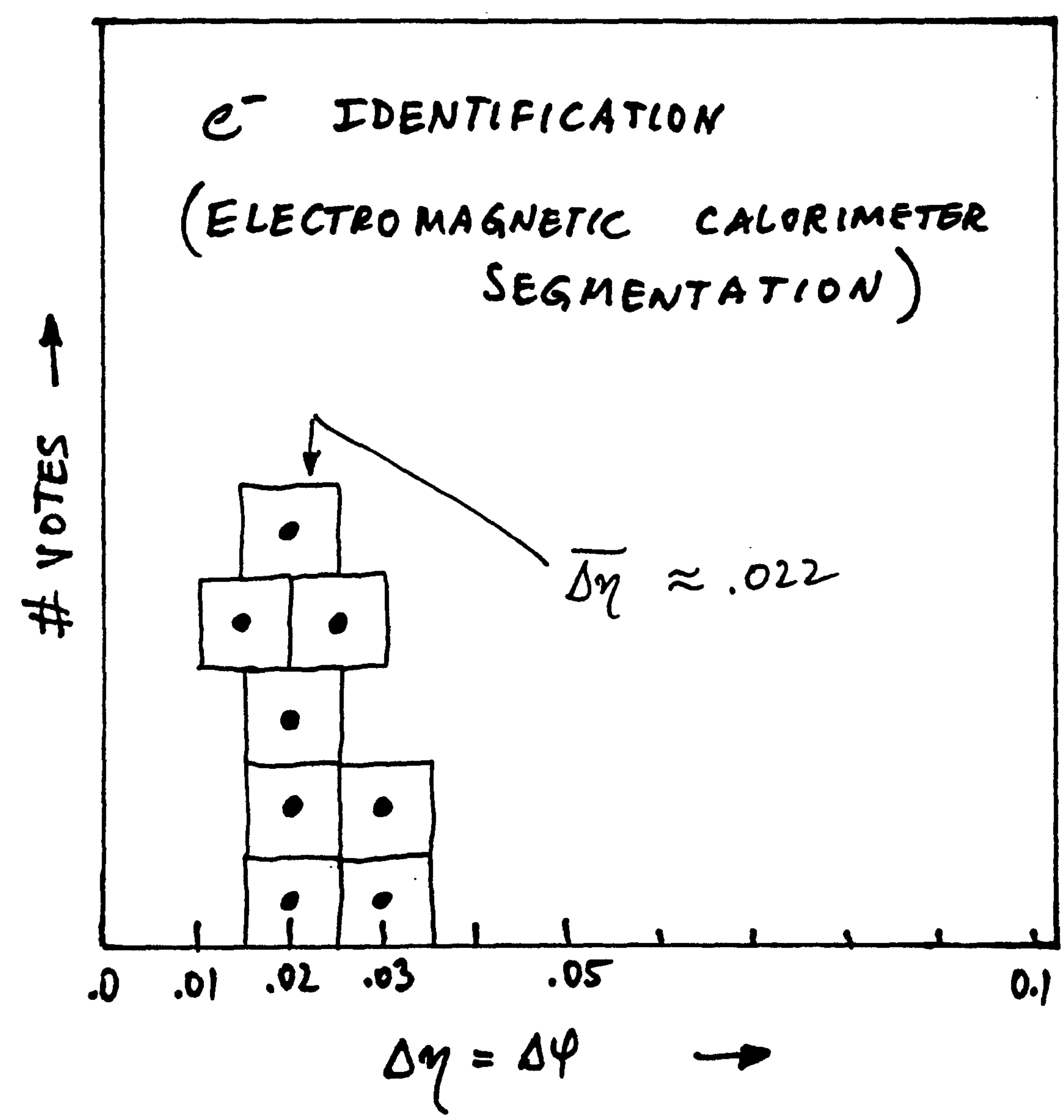


Figure 2. ELECTRON IDENTIFICATION.

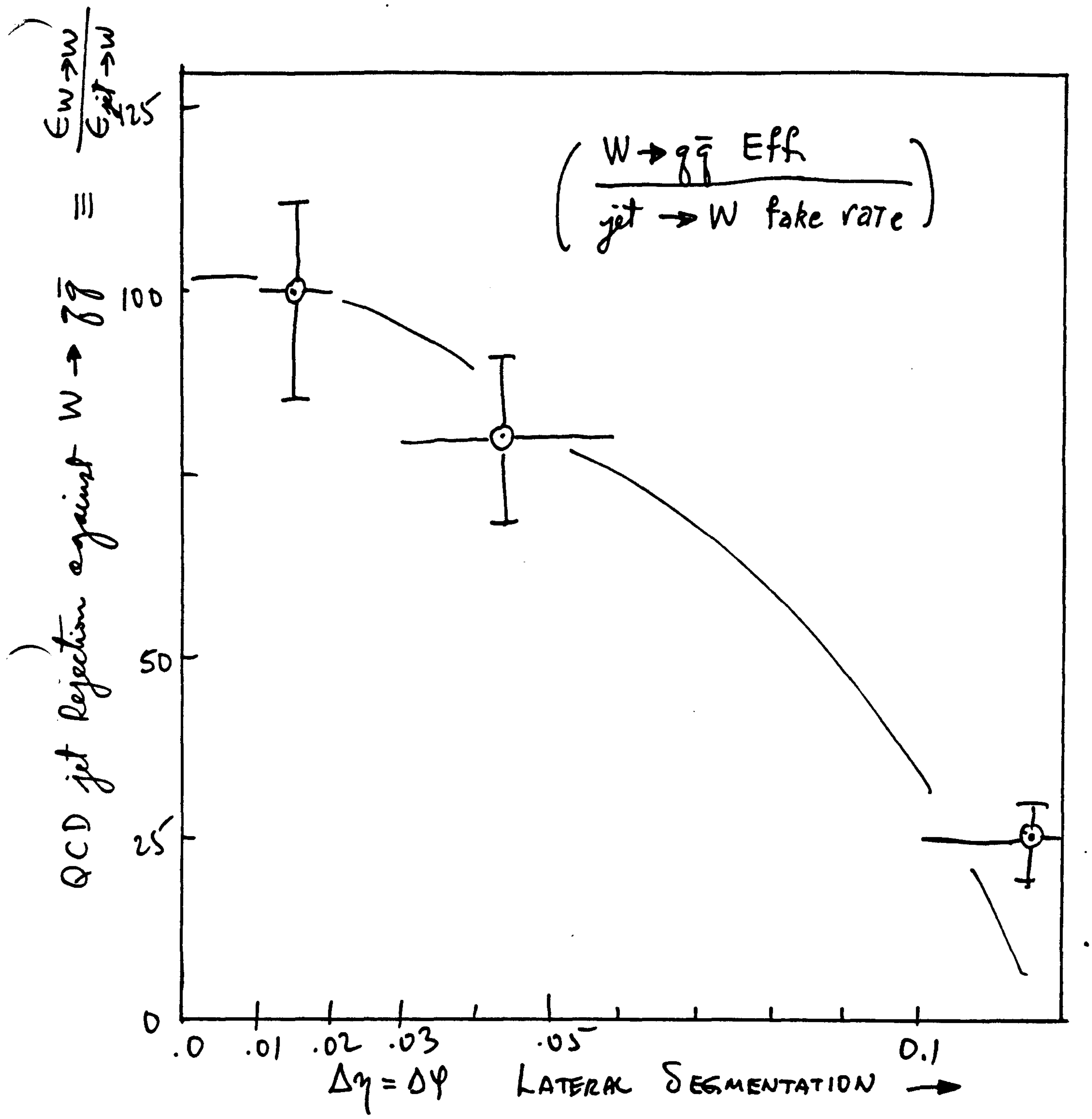
W → q q̄ Eff.
jet → W fake rate
QCD jet Rejection against W → q q̄ ≡ ε W→W / ε jet→W
100
50
25
0
.0
.01
.02
.03
.05
0.1
Δη = Δφ LATERAL SEGMENTATION →

Figure 3.